

The Environmental Impacts of River Sand Mining: A Comprehensive Review of Physical, Biological, Chemical, and Anthropogenic Effects

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Abstract - The requirement for construction sand is increasing at an alarming pace, and it is anticipated that this resource will be depleted by the year 2050. Construction sand, henceforth referred to as ‘sand’, such as rivers and serves as a provisioning ecosystem service. Even when extraction is conducted under regulated conditions, removing sand from the riverbed and banks has environmental consequences. Unfortunately, many countries do not have regulations governing sand mining and the combination of high demand leads to indiscriminate and illegal extraction practices. To formulate effective policies for the sustainable extraction of river sand, it is essential to gather both qualitative and quantitative data regarding the impacts of river sand mining. This paper consolidates the various consequences of river sand mining on the physical, biological, chemical, and anthropogenic environment through a systematic literature review. Widespread and frequently cumulative impacts are observed. Riverbed expansion and lowering are the main factors on the physical environment. The overall impact on the biological environment is a decrease in biodiversity, which affects everything from the aquatic and coastal flora and fauna to the entire floodplain region. Pollution has a negative impact on the chemical environment by lowering the quality of the soil, water and air. Infrastructure damage, unfavorable working conditions for employees, restricted water access, and agriculture losses are some of the consequences on the anthropogenic environment. The results of this study highlight the seriousness and urgency of the issue as well as the intricate and cascading nature of the consequences of river sand mining. At the conclusion of this study, a set of recommendations for a worldwide agenda on sustainable sand extraction is put out based on the effects discovered and the four habitats. Quantifying the consequences that have been observed and creating science-based policies for sustainable mining should be the top priorities for future research.

Keywords: Extraction of Sand, Quality of Water, Biodiversity, and Ecosystem.

AN ENVIRONMENTAL CRISIS OF GLOBAL CONCERN:

After water, sand is the second most extensively used natural resource worldwide. Due to its increasing economic importance, it is often referred to as “the new gold.” However, the uncontrolled and excessive extraction of sand is causing severe damage to terrestrial and aquatic ecosystems, threatening biodiversity and altering natural landscapes across the world [11]. As a valuable provisioning ecosystem service, sand is primarily obtained from rivers, streams, and coastal environments where sediment is naturally transported and deposited by water. The construction sector accounts for the largest share of sand consumption because concrete occupies nearly 75% sand. Approximately 200 tons of sand is needed to construct a single house, 30,000 tons for one kilometre of highway, and around 12 million tons for a nuclear power plant [32]. This rapidly increasing demand has accelerated sand mining, making it one of the most pressing global environmental challenges [5].

A global ban on sand mining is not a practical solution because the demand for sand continues to rise rapidly, driven largely by urbanization and infrastructure development [20]. Global sand consumption increased approximately 23-fold between 1900 and 2010, and demand is projected to reach nearly 82 billion tons by 2060 [51 & 19]. At present, about 50 billion tons of sand is extracted each year, which is roughly twice the amount that natural geological processes can replenish over the same period [32]. Since sediment formation and

replenishment require thousands of years, current extraction rates are unsustainable. If this trend continues, studies suggest that accessible sand resources could face severe depletion as early as 2050 [50].

India is one of the world's largest consumers of sand, with demand driven by rapid urbanization, population growth, and large-scale infrastructure development. River sand is the preferred material for concrete and construction, making it an essential natural resource for the housing and transportation sectors. As construction activities continue to expand, both legal and illegal river sand mining have increased significantly, placing immense pressure on river ecosystems and freshwater resources (UNEP, 2019; Rentier & Cammeraat, 2022). The ecological impacts of excessive sand extraction are well documented across Indian rivers. In Kerala, extensive sand mining in the Periyar, Chalakudy, and Muvattupuzha Rivers has resulted in riverbed incision, channel widening, bank erosion, lowering of groundwater tables, and degradation of aquatic habitats [29]. These geomorphological changes have reduced the natural sediment balance of rivers and affected the availability of water for domestic, agricultural, and ecological purposes.

Similar environmental degradation has been observed in other parts of India. Studies on the Kangsabati River in West Bengal reported that uncontrolled sand mining has accelerated channel instability, altered river morphology, and increased the vulnerability of surrounding communities to erosion and water scarcity (Bhattacharya & Das Chatterjee, 2021). These findings demonstrate that unsustainable sand mining has become a major environmental challenge in India, emphasizing the need for effective regulation and sustainable river basin management [56 & 58].

Mining activities inevitably alter natural environments, but their impacts become far more severe when adequate legislation and regulatory mechanisms are absent. The extraction of sand, while providing an important ecosystem service, can simultaneously reduce the availability of other ecosystem services by disrupting river morphology, aquatic habitats, groundwater systems, and water quality [20 & 26]. Recent reports by the United Nations Environment Programme (UNEP) and the World Wildlife Fund (WWF) highlight the critical shortage of reliable data and the limited policy frameworks needed to ensure the responsible extraction and sustainable use of river sand [20 & 26]. To develop effective and sustainable management strategies, a comprehensive understanding of the scale and consequences of river sand mining is essential. Therefore, this paper aims to provide an integrated overview of the environmental impacts of river sand mining by examining its effects on the physical, biological, chemical, and anthropogenic environments. By synthesizing evidence across these four dimensions, the study offers a comprehensive framework that can support global policy development for sustainable sand extraction. Understanding these environmental impacts is fundamental to identifying appropriate prevention, mitigation, and restoration measures. Following a brief theoretical background, the findings are presented according to each environmental category. The methodology of the systematic review is provided as supplementary material, while the overall findings, conclusions, and recommendations are discussed in the final section of the paper.

The Origin Of Sand:

To evaluate the environmental impacts of river sand mining, it is essential to understand the natural processes of sediment generation, transport, and deposition within river systems. Although sand appears to be an abundant natural resource, not all types of sand are suitable for construction. Desert sand, which is shaped by prolonged wind erosion, has smooth and rounded grains that reduce its binding capacity in concrete. In contrast, river sand consists of angular particles with diverse grain sizes and favorable mineral composition, making it the preferred material for construction and infrastructure development [38].

Sediment Supply:

The characteristics of river sediment are largely influenced by the geographical setting of the river and the nature of its catchment area. Sediment properties vary depending on the dominant source areas, while factors such as parent rock material, soil type, topography, and geomorphological conditions determine the mineral composition, grain size, durability, and overall quantity and quality of the sediment [16]. Sediment sources are finite and require long periods to replenish naturally. The delivery of sediment into river channels primarily occurs through three natural processes i.e., i. mass wasting including landslides and slope failures, ii. erosion of hill slopes by surface runoff, and iii. Erosion of river beds and banks. Together, these processes maintain the sediment balance that is essential for sustaining river morphology and ecological functioning [16].

Sediment Transport:

The movement of eroded sediment from upstream side mountainous regions to downstream side floodplains is commonly described as the “conveyor belt effect” by [27]. Once sediment enters into a river channel, it is transported in two primary forms: suspended load and bed load. Suspended load consists of fine-grained particles that remain suspended in flowing water and settle only when the water velocity becomes negligible. In

contrast, bed load includes coarser materials that move along the riverbed by rolling, sliding, bouncing, or dragging through the processes of traction and saltation [15]. Among these mechanisms, saltation is the dominant mode of sand transport. Bagnold (1973) demonstrated that bed-load movement is governed by complex hydraulic conditions, particularly flow velocity and water depth, which strongly influence a river's capacity to transport sediment. Rivers with greater depth or steeper gradients generally possess higher discharge and a greater ability to carry larger sediment particles. Although sediment transport remains a complex process with considerable scientific uncertainty, it is generally accepted that increasing flow velocity enables the transport of progressively coarser materials [10, 15, &16]. During transport, sediment particles undergo continuous mechanical wear through abrasion and collision, gradually reducing their size and altering their shape [10, 15, & 16]. Consequently, sand transported over longer distances becomes more rounded and weathered, making it less suitable for high-quality concrete and cement production.

Sediment Deposition and Suitability for sand mining:

As sediment is transported downstream, individual grains are continuously subjected to abrasion and collision, causing them to become progressively smaller, smoother, and more rounded. Because a river's flow velocity is directly related to its sediment-carrying capacity, a decrease in channel gradient is typically accompanied by a reduction in grain size and improved sediment sorting [16]. Consequently, coarse materials such as gravel dominate the upper reaches of a river, whereas finer sediments, including sand, become increasingly abundant toward the downstream sections of the longitudinal river profile [16]. This downstream variation in sediment characteristics is a key factor influencing river sand mining. Mining operators generally target river reaches where sand possesses the optimum grain size, angularity, and mineral composition required for construction [38]. Extraction in upstream areas often requires costly processing to separate sand from coarse sediments, while sand collected too far downstream may be excessively rounded or contain less desirable mineral properties. Furthermore, because sand is a heavy and expensive material to transport, extraction is typically carried out as close as possible to construction sites in order to minimize transportation costs and improve economic efficiency.

TYPES OF RIVER SAND MINING

River sand mining is the process of extracting sand from river channels and associated floodplain deposits. Although sand is an essential resource for construction, its extraction inevitably alters the natural river environment. The magnitude of these impacts depends on the rate of extraction, the mining method adopted, and the manner in which the operation is carried out. Environmental degradation becomes significant when sand is removed at a rate that exceeds the river's natural capacity for sediment replenishment [21]. Sustainable extraction practices are therefore essential to maintain sediment balance and protect river ecosystems. River sediment used for mining is generally obtained from two principal sources: (i) active river channels and (ii) floodplain terraces. Depending on the location and extraction technique, river sand mining is commonly classified into the following five methods:

1. Channel-wide instream mining: extraction across the entire width of the active river channel.
2. Wet pit excavation: removal of sand from submerged pits below the water level.
3. Dry pit excavation: extraction from exposed floodplain or terrace deposits above the water table.
4. Bar excavation: mining of sand from river bars located within the channel.
5. Bar skimming: shallow removal of sand from the surface of river bars while leaving the lower sediment layer relatively undisturbed.

These mining methods differ considerably in their environmental impacts, with instream extraction generally posing the greatest risk to river morphology, aquatic habitats, and groundwater systems.

Among the five mining methods, channel-wide instream mining is considered the most destructive because sand is extracted across the entire active river channel, particularly during the dry season [38]. Pit excavation involves removing sand from the riverbed or floodplain, creating deep pits that alter channel morphology. When extraction occurs below the water table using suction pumps and dredging equipment, it is referred to as wet pit mining [38]. In contrast, dry pit mining is carried out in dry or ephemeral river channels using excavators, scrapers, or manual labor [37]. Less intensive methods include bar skimming and bar excavation. Bar skimming removes only the surface layer of exposed sand bars located above the water table, allowing extraction at a safer distance from the active channel [47]. Bar excavation, however, involves mining the downstream end of sand bars and is often followed by expansion into adjacent floodplains and river terraces [37]. Although these mining techniques differ in their intensity and operational methods, all of them produce environmental impacts that

affect one or more components of the physical, biological, chemical, and anthropogenic environment. Accordingly, the impacts discussed in this study are classified into these four environmental categories.

RIVERBED DEGRADATION:

Indiscriminate river sand mining significantly alters the morphology of river channels by disrupting the natural balance between erosion and sediment deposition. Although sand extraction occurs at specific locations, its impacts extend longitudinally along the river, producing cumulative changes in channel stability and sediment dynamics. When sediment is removed from the riverbed, a sediment deficit is created, causing the river to adjust by transporting sediment from upstream reaches to restore equilibrium [17 & 25]. This upstream adjustment accelerates the erosion of both the riverbed and river banks, leading to progressive channel incision and bank instability. Two primary mechanisms are responsible for intensifying riverbed degradation: head cutting, in which erosion migrates upstream from the excavation site, and hungry water, where sediment-deficient flow gains greater erosive capacity and scours the channel downstream. Together, these processes contribute to long-term degradation of river morphology and sediment balance. Excavation of sand from the riverbed creates nick points (abrupt changes in bed elevation) that initiate the process of head cutting. As these nick points progressively migrate upstream, they accelerate riverbed and bank erosion, generating additional sediment that is subsequently transported downstream [27]. This mechanism is illustrated in Fig.1.

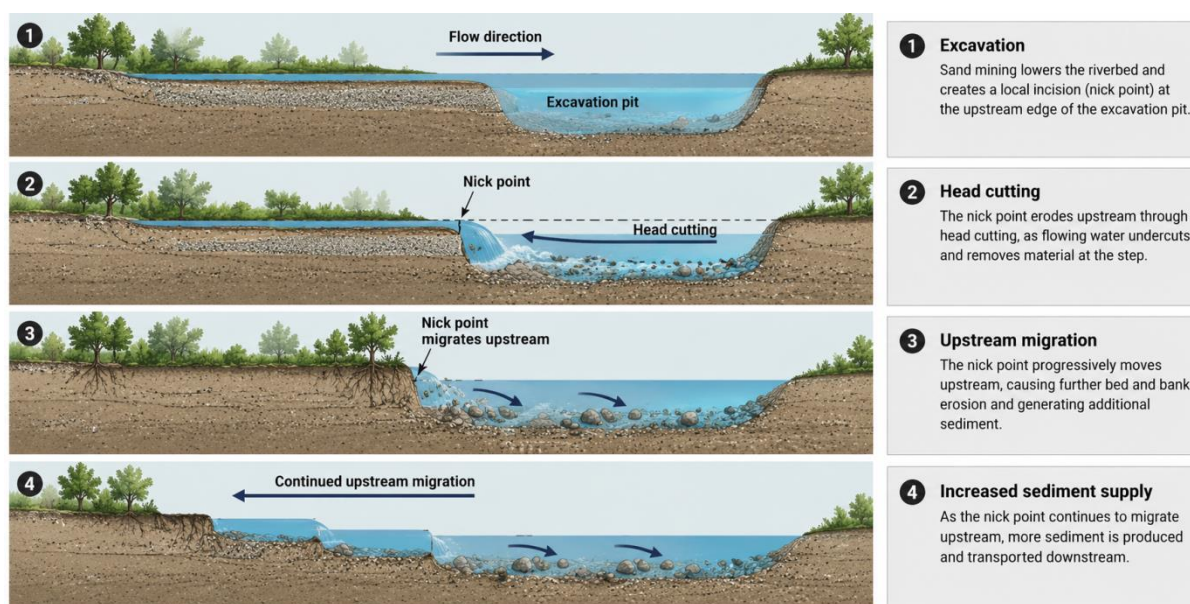


Figure1. Schematic illustration of head cutting and upstream migration of nick points induced by river sand mining

Hungry Water and Cross-Sectional Channel Changes:

A distinctive consequence of river sand mining is the hungry water phenomenon, in which sediment removed from the river creates a sediment-starved flow with greater erosive capacity. Although the eroded sediment generated by upstream head cutting is often re-deposited within the excavation pit, the water leaving the pit contains less sediment and therefore has more energy available to erode the downstream riverbed [9,27,37]. As described by Kondolf (1997), interruption of the natural continuity of sediment transport through gravel or sand extraction produces sediment-deficient flow that accelerates channel degradation. River sand mining also alters the cross-sectional geometry of rivers. Pit excavation deepens the riverbed, while bar skimming and bank undercutting promote channel widening by increasing bank instability [17,18, & 28]. An additional mechanism of channel enlargement is pit capture, which occurs when wet mining pits excavated near the active channel become connected to the river after the separating sediment wall collapses during high-flow events [22]. Together, head cutting, hungry water, and pit capture contribute to progressive river incision, bank erosion, and long-term changes in channel morphology.

A quantitative assessment of Indian rivers has demonstrated that excessive river sand mining causes riverbed incision, resulting in channel deepening, bank instability, and an increased risk of riverbank collapse. Studies conducted in the Periyar, Chalakudy, and Muvattupuzha rivers of Kerala revealed significant changes in channel morphology, including deepened and widened cross-sections following intensive sand extraction [37 & 38]. Figure 2 illustrates longitudinal, cross-sectional, and hydrological impacts of river sand mining. As the riverbed becomes deeper and wider, the hydraulic characteristics of the channel are altered. Assuming a constant

inflow, the modified channel geometry reduces flow velocity within excavation pits, promoting localized sediment deposition while enhancing erosion in adjacent reaches. More importantly, riverbed lowering reduces the river water level, which consequently lowers the surrounding groundwater table. This decline in groundwater can restrict the recharge of shallow aquifers, reduce water availability for agriculture and domestic use, and alter the natural low-flow regime of rivers [37]. Similar hydrological and geomorphological changes have been documented in several Indian river systems, indicating that indiscriminate sand mining disrupts channel stability, groundwater–surface water interactions, and the long-term sustainability of riverine environments [38].

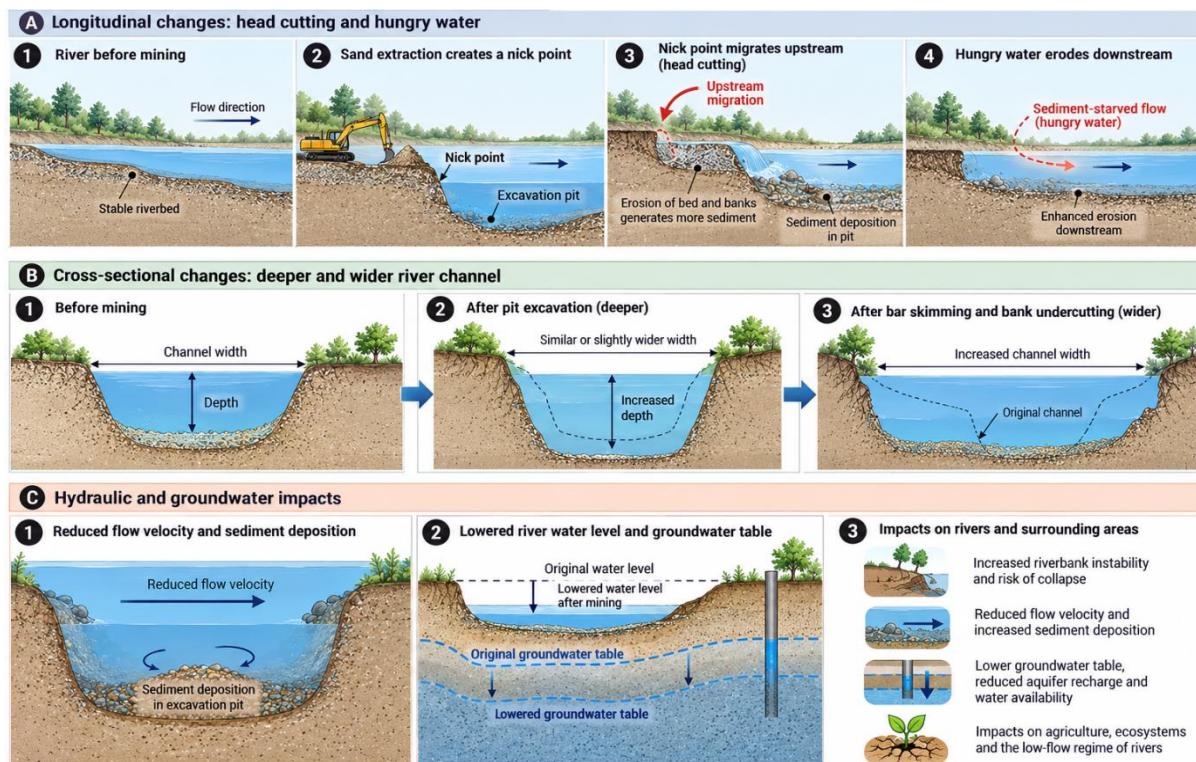


Figure2: Conceptual illustration of longitudinal, cross-sectional, and hydrological impacts of river sand mining on river morphology and ground water systems.

Changes in Sediment Characteristics:

In addition to altering river morphology, indiscriminate river sand mining significantly modifies the grain-size composition and sediment characteristics of river channels. Studies conducted in the Periyar, Chalakudy, and Muvattupuzha rivers of southwest India reported a progressive coarsening of the riverbed due to the continuous removal of fine and medium sand fractions from upstream reaches [37,38]. As finer sediments are selectively extracted, the remaining channel bed becomes increasingly dominated by coarse sand, gravelly sand, and sandy gravel. This selective removal accelerates the natural processes of sediment sorting and transport. Fine sediments eroded from upstream are transported and deposited in downstream sections, while the sediment deficit created within the mined reach enhances the erosive action of sediment-starved (hungry) water during high-flow conditions [27, & 37]. Consequently, the river loses its natural sediment balance, leading to continued channel degradation and altered sediment dynamics. The impacts of reduced sediment supply are not confined to rivers alone. Decreased delivery of fluvial sediment to coastal environments limits the natural replenishment of beaches and dunes, increasing their susceptibility to erosion and reducing their capacity to protect coastal communities from storm surges, tsunamis, and sea-level rise [39]. Figure 3 shows conceptual illustration of river sand mining.

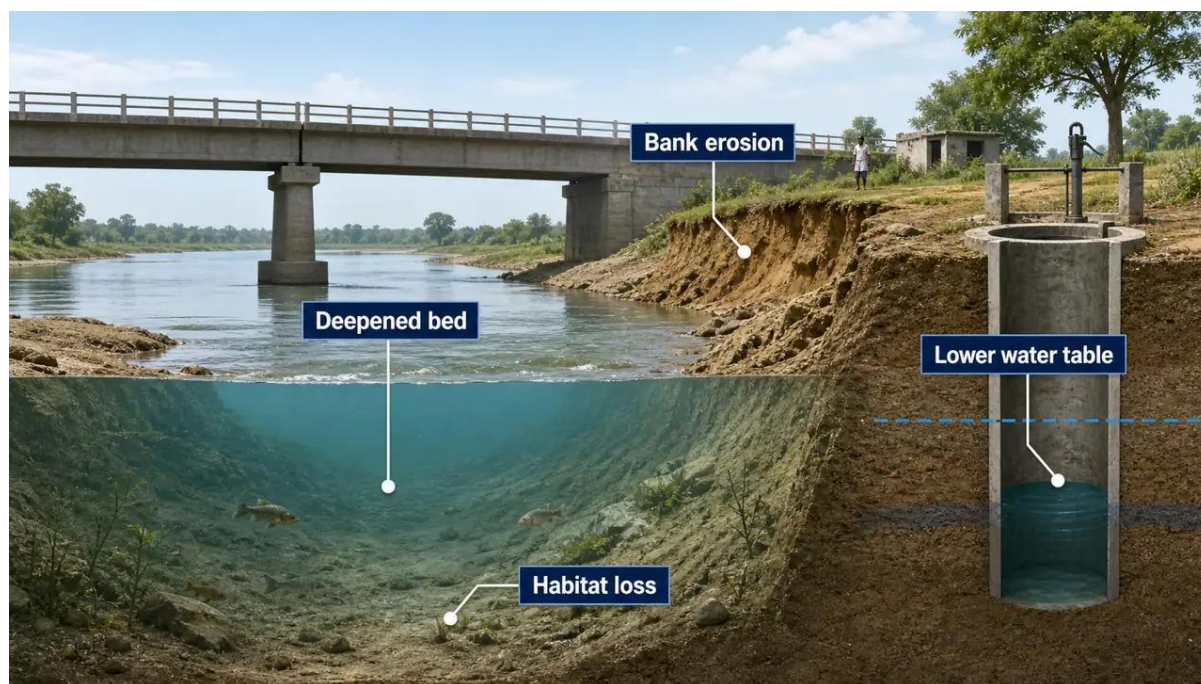


Figure 3: Conceptual illustration of longitudinal, cross-sectional, and ground water impacts as it logically follows the discussion of river morphology and completes the physical impacts section.

Biological Environment:

The biological impacts of river sand mining extend well beyond the immediate extraction sites and affect the structure and functioning of entire river ecosystems. Although research on the ecological consequences of sand mining remains limited, existing studies indicate that its effects on aquatic biota, riparian vegetation, and freshwater biodiversity are substantial and often cumulative [40, 37]. River sand mining alters habitat characteristics by modifying channel morphology, increasing turbidity, and disturbing spawning and feeding grounds for aquatic organisms. These changes reduce habitat quality and species diversity, leading to declines in fish, benthic macroinvertebrates, and other riverine fauna. Because these organisms occupy different trophic levels, the ecological disturbance can propagate throughout the food chain, affecting ecosystem productivity and the delivery of essential ecosystem services [15]. The magnitude of these biological impacts varies among river systems depending on mining intensity, river characteristics, and ecological sensitivity. Nevertheless, the available evidence consistently demonstrates that indiscriminate sand mining contributes to the degradation of freshwater biodiversity and threatens the long-term ecological integrity of riverine environments.

A stable riverbed is one of the conditions that ensures the (long-term) survival of many species. The sand layer on the solid riverbed is a hospitable environment for many microorganisms. Removal of the sand means instability and a loss of habitat for these organisms [54]. Aquatic vegetation and microorganisms play an important role in maintaining the balance and health of the river's biological environment and when the balance in this ecosystem is disturbed it can be pushed to or crossed over a tipping point [37]. The extraction of sand stirs up the water and increases turbidity. This, in turn, blocks sunlight and reduces respiration and photosynthesis, but can also block respiratory organs of aquatic animals [9 & 37]. When deposited, the stirred up particles like silt and clay form a blanket on the river bed which can smother microorganisms such as diatoms, macro invertebrates, benthic algae or fish eggs [9 & 37]. [49] Studied the average abundance of benthic organisms in the Achonkivil River, India. The widening of the riverbed can result in a shallow stream bed which often results in braided river flow. This type of flow hinders the movement of fishes between flows and pools [30 & 17]. Studied the effects of sand mining in Puyong Lake, China and stated that the echolocation of the red-listed finless porpoise may be affected by dredging induced noise. [33] Conclude in their research that river sand mining threatened the Ganges river dolphin to the verge of extinction. These are no exceptional cases unfortunately and they can be seen in many environments that have been degraded by river sand mining.

Habitat Degradation and Aquatic Biodiversity:

A stable riverbed provides essential habitat for microorganisms, benthic organisms, aquatic vegetation, and fish, thereby supporting the long-term ecological health of river ecosystems. Indiscriminate river sand mining destabilizes this habitat by removing the sand layer that serves as a substrate for microbial communities and other bottom-dwelling organisms, resulting in the loss of habitat and reduced biological productivity [37 & 54].

Sand extraction also increases water turbidity by suspending fine sediments such as silt and clay in the water column. Elevated turbidity reduces light penetration, thereby limiting photosynthesis and respiration in aquatic vegetation and algae, while suspended particles may clog the respiratory organs of aquatic fauna [9 & 37]. After settling, these fine sediments form a blanket over the riverbed, smothering diatoms, benthic algae, macro invertebrates, and fish eggs, ultimately reducing the abundance and diversity of aquatic organisms [9 & 37].

Studies on the Achankovil River in Kerala have reported a significant decline in benthic macro invertebrate abundance in reaches affected by intensive sand mining [49]. Furthermore, channel widening caused by bar skimming and bank undercutting often produces shallow, braided channels that restrict fish movement between pools and flowing reaches, thereby disrupting feeding, spawning, and migration pathways [17, 30]. These biological disturbances extend throughout the aquatic food chain. The degradation of benthic habitats reduced primary productivity, and fragmentation of river channels collectively threaten freshwater biodiversity and diminish the ecological functions and ecosystem services provided by riverine environments.

The degradation of aquatic habitats caused by river sand mining has cascading effects throughout the riverine food chain. A substantial decline in benthic macro invertebrates, which form the foundation of freshwater food webs, has been reported in sand-mined rivers [49, 54]. As these organisms serve as a primary food source for many fish species, their reduction affects higher trophic levels and ultimately threatens fisheries and human populations that depend on aquatic resources.

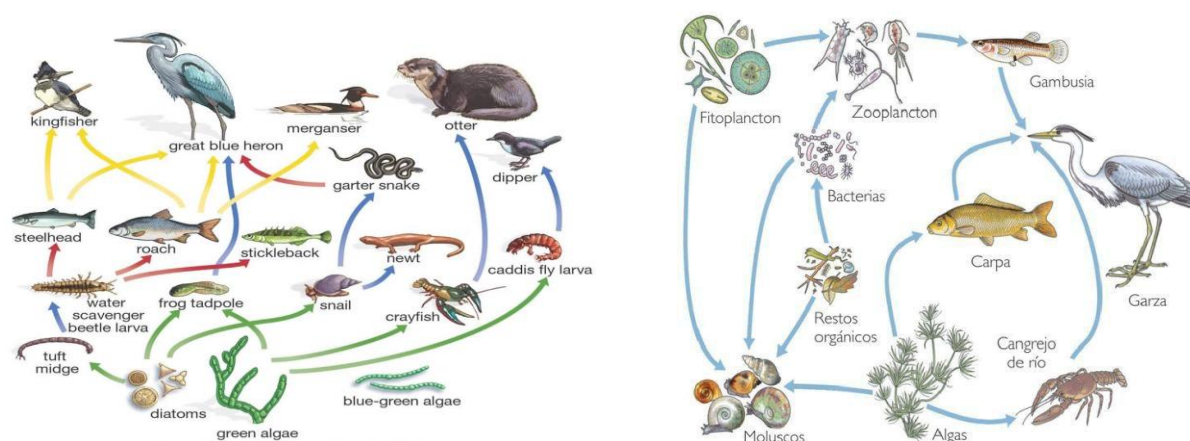


Figure 4a & 4b: Conceptual illustration of the cascading effects of river sand mining on the aquatic food chain and freshwater biodiversity.

The ecological impacts are not limited to aquatic organisms alone. Many terrestrial species, including aquatic insects, amphibians, birds, and other wildlife that rely on river ecosystems for food and habitat, are indirectly affected by the loss of aquatic biodiversity [37]. Furthermore, disturbance of the natural ecological balance may create favorable conditions for the establishment and spread of invasive species, leading to further declines in native biodiversity and ecosystem resilience.

Impacts on Riparian Vegetation:

River sand mining affects not only aquatic fauna but also the riparian vegetation that supports the ecological integrity of river corridors. Vegetation is directly removed during bar skimming, excavation, and the construction of access roads and transport infrastructure, resulting in the destruction of habitats both above and below the ground surface [30,37, &39]. The loss of riparian plants also weakens riverbank stability, making banks more susceptible to erosion and accelerating sediment loss. A further indirect impact arises from the lowering of the groundwater table caused by riverbed incision. Declining groundwater levels reduce soil moisture in floodplains and riverbanks, leading to the deterioration or death of riparian vegetation and wetland plant communities [30, 39, & 47]. This loss of vegetation further destabilizes channel margins and diminishes the ecological resilience of the river system.

Riparian vegetation is essential for maintaining the Shaded Riverine Aquatic (SRA) habitat, which provides shade, bank stabilization, organic litter, and nutrient-rich conditions for numerous aquatic and terrestrial organisms [37]. Degradation of this habitat disrupts ecological processes, reduces habitat quality, and threatens the overall biodiversity and functioning of riverine ecosystems.

Chemical Environment:

River sand mining does not significantly alter the chemical composition of sand itself; however, it has profound effects on the water quality of river systems. During wet pit mining, dredging and excavation suspend fine

organic and inorganic sediments, increasing turbidity and the concentration of total suspended solids (TSS) in the water column [9, & 37]. These suspended particles carry nutrients and minerals that are naturally transported downstream, and their redistribution modifies the nutrient dynamics of both riverine and coastal ecosystems. The removal of sediment also reduces the transport of nutrient-rich particles within the river. Fine sediments excavated from the channel are often deposited on downstream sand bars, where the accumulated nutrients may promote the establishment of riparian vegetation and the gradual development of floodplain habitats. Such changes have been documented along the Periyar River in Kerala, demonstrating how sand mining alters the natural distribution of sediments and nutrients within the river system [37 & 38].

In addition to sediment redistribution, mining operations introduce chemical pollutants through the use of heavy machinery. Fuel and oil spills, together with exhaust emissions from excavation and transportation equipment, degrade both water and air quality, posing risks to aquatic organisms, riparian vegetation, wildlife, and nearby human populations [30 & 38]. River sediments may also accumulate contaminants derived from upstream anthropogenic activities, including mining, agriculture, and industrial discharge. Fine-grained sediments are particularly effective at adsorbing heavy metals such as cadmium (Cd) and other toxic elements, making the quality of mined sand an important consideration before its use in construction [23 & 46]. Studies from various river systems have reported elevated concentrations of heavy metals and increased levels of turbidity, suspended solids, iron, magnesium, zinc, and manganese in areas affected by intensive sand mining, indicating a deterioration of river water quality and potential risks to ecosystem and human health [1].

Anthropogenic Environment:

River sand mining has significant impacts on the anthropogenic environment, including human infrastructure, agriculture, livelihoods, and local communities. Riverbed deepening and channel widening caused by excessive sand extraction create both vertical and lateral channel instability, increasing erosion and weakening riverbanks. As a result, buildings, roads, bridges, embankments, and buried pipelines located near rivers become vulnerable to undermining and structural failure [30 & 38]. The instability of riverbanks also poses serious risks to flood protection structures. A risk assessment conducted in the Achankovil River Basin of Kerala demonstrated that sand mining substantially reduced the stability of levee slopes, with the probability of slope failure nearly doubling under mining conditions [52]. These findings highlight the growing threat to infrastructure and settlements situated along river corridors. Agricultural productivity is similarly affected through the lowering of groundwater levels. As riverbed incision reduces the surrounding water table, irrigation wells and traditional water-lifting structures may no longer reach groundwater, resulting in reduced irrigation potential, declining crop yields, and the loss of cultivable land [37]. In addition, the degradation of aquatic habitats and fish breeding grounds has led to reduced fish populations, causing significant declines in the productivity of local fisheries and adversely affecting the livelihoods of river-dependent communities [30,37 & 38].

Overall, the anthropogenic impacts of river sand mining extend beyond environmental degradation, creating long-term economic, social, and infrastructure challenges for communities that depend on healthy and stable river systems.

Impacts on Human Health and Livelihoods:

River sand mining also has significant consequences for human health and rural livelihoods. The lowering of groundwater levels reduces the availability of water for irrigation, and similar conditions have been reported in the Manimala River, where declining groundwater adversely affected agricultural productivity [38]. As irrigation structures fail to reach the lowered water table, crop yields decrease and the productivity of agricultural land is reduced. In addition, sand mining deteriorates river water quality by increasing turbidity and the concentration of heavy metals, with several studies reporting contaminant levels that exceed the World Health Organization (WHO) drinking water standards [30]. This poses serious risks to communities that depend on river water for drinking, cooking, and irrigation. Excavation pits created during sand mining often retain stagnant water during the rainy season, providing ideal breeding habitats for mosquitoes and other water-borne insects [30]. Consequently, sand mining indirectly increases the risk of vector-borne diseases and negatively affects the health and well-being of nearby populations. Furthermore, the increasing scarcity and economic value of river sand have contributed to the expansion of illegal sand mining and unauthorized trade, creating social, economic, and governance challenges in many river basins [51].

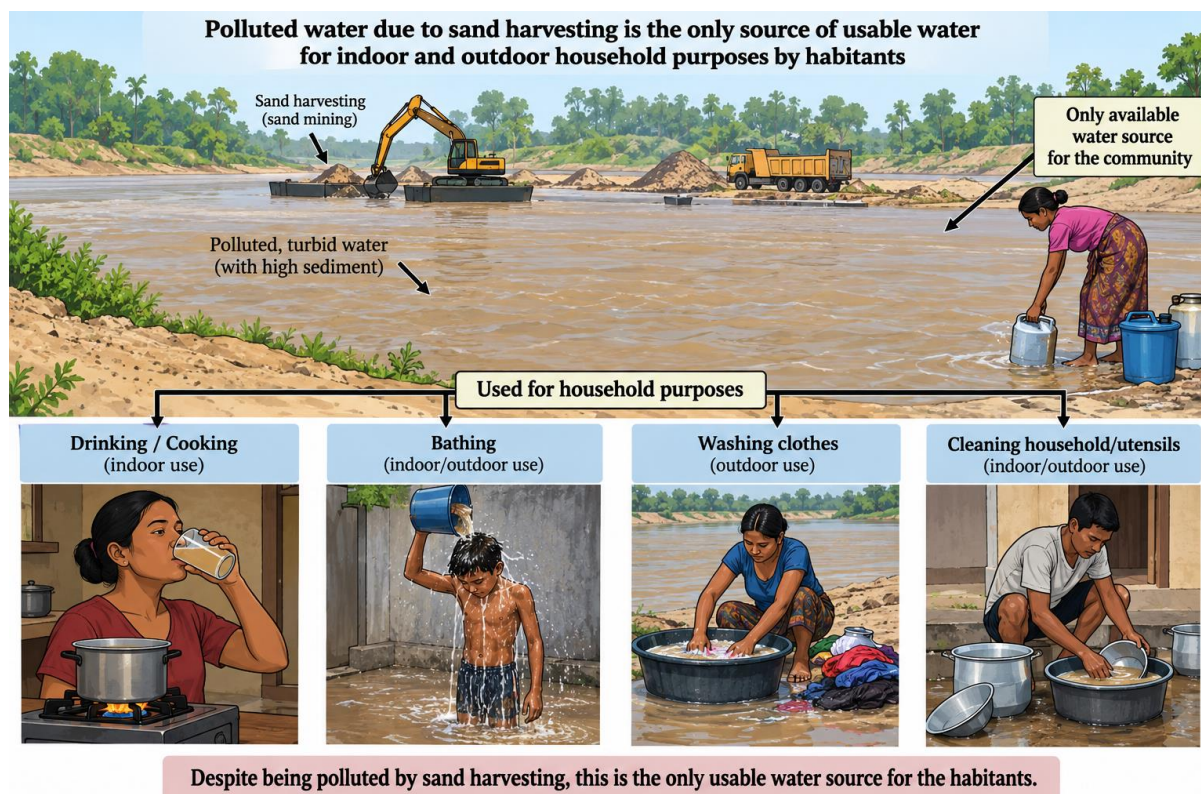


Figure 4: Impacts of river sand mining on rural household water use and community dependence on polluted river water.

Illegal Mining, Occupational Health, and Community Safety:

Sand is a common-pool natural resource that is relatively easy to extract, making it highly vulnerable to illegal mining and weak regulatory control [42]. In many Indian river basins, unauthorized extraction from rivers such as the Periyar, Manimala, and Bharathapuzha has become a major challenge, resulting in uncontrolled depletion of river sand and significant environmental degradation [37,38]. Illegal sand mining is frequently associated with organized criminal networks, commonly referred to as the “Sand Mafia”, and has been reported in numerous countries [13,51]. Conflicts over access to sand resources have resulted in loss of life and serious social tensions in regions including India, Kenya, and Nigeria [13]. Moreover, deep excavation pits left within river channels create major public safety hazards, with several drowning incidents reported in mined rivers [43 & 45].

Mining operations also expose workers and nearby communities to occupational and environmental health risks. Dust generated by excavation and transportation machinery can cause respiratory irritation, while contaminated river water is often used for drinking in areas where alternative water sources are unavailable [33]. Although the sand mining sector provides employment opportunities, its long-term environmental degradation, unsafe working conditions, and adverse impacts on local livelihoods often outweigh its short-term economic benefits.

CONCLUSIONS AND RECOMMENDATIONS:

The impacts of river sand mining extend far beyond the immediate extraction sites, producing cumulative changes throughout river ecosystems. Its effects on the physical and biological environment are often gradual and interconnected, making them difficult to measure and assess accurately. Nevertheless, excessive sand extraction commonly results in riverbed degradation, habitat destruction, and a significant decline in both geological and biological diversity. In addition to ecological damage, river sand mining has profound chemical and anthropogenic consequences. Increased turbidity, deteriorating water quality, and declining groundwater levels directly affect communities that depend on rivers for drinking water, agriculture, fisheries, and other livelihood activities. These environmental changes often lead to substantial social and economic hardships for populations living in riverine areas. The complex and cascading nature of these impacts highlights the urgency of adopting sustainable sand resource management. Many of the world's largest sand-consuming nations, particularly in rapidly developing regions of Asia and Africa, continue to face challenges related to weak governance, inadequate monitoring, and limited regulatory enforcement. Effective management therefore

requires science-based policies supported by strong institutional frameworks and active enforcement. As a vital provisioning ecosystem service, sand plays an essential role in supporting human development; however, its unsustainable extraction disrupts an entire network of interconnected ecosystem services. Sustainable mining policies should integrate physical, biological, chemical, anthropogenic, political, and economic considerations while recognizing the interests of multiple stakeholder groups. Such an integrated approach is essential for minimizing environmental degradation, conserving ecosystem services, and ensuring the long-term sustainability of river systems. To promote sustainable river sand mining and reduce environmental degradation, the following measures are recommended:

1. Sustainable resource management: Permit sand extraction only in scientifically assessed zones where natural sediment replenishment can sustain mining, and encourage the use of alternative construction materials.
2. Strengthened governance: Implement strict licensing, environmental impact assessments, buffer zones around critical infrastructure, and seasonal restrictions to protect aquatic ecosystems.
3. Continuous monitoring: Establish mandatory pre- and post-mining surveys using remote sensing, GIS, and periodic field assessments to monitor river morphology, water quality, and biodiversity, enabling adaptive management of mining activities.

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